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Letter
Circular
LC 363

THE PROPERTIES AND TESTING OF FOUNDRY SANDS

I. Introduction

The use of sands and other materials as a means for putting metals into useful forms by casting is known to date from the time of the earliest written records and, with a high degree of certainty, can be projected back far into prehistoric times. Although casting is one of the oldest of all metallurgical operations, it has been until very recently one of the most conservative and has been guided largely by tradition and custom. As an example, it is only within the past two decades that a systematic investigative study has been made of the essential and characteristic properties of foundry sands.

The greater precision now required in foundry work, resulting in large measure from competition with other processes, has necessitated careful study and control of the various factors which influence the production of good metal castings. The mold into which the metal is poured and the sand out of which the mold is formed rank foremost among these factors. A suitable and satisfactory mold is a prime requisite in all successful foundry operation. No substitute for it exists.

The Bureau of Standards receives many inquiries relating to new sand deposits, the reclamation of used sands, as well as the technique necessary for developing the best properties for foundry use of any particular grade of sand. The immediate aim of this circular is to furnish information on the characteristic properties of typical commercial foundry sands as determined by approved test methods. Much of the best available information on the properties and testing of foundry sands has resulted directly from the extensive research sponsored by the American Foundrymen's Association and much of the information presented herewith has been obtained in the Bureau's co-operative studies carried out with that organization.

Most of the results used later to illustrate the characteristics of foundry sands have been taken from tests of representative commercial sands which have been carried out as part of this Bureau's work. The use of these data is not to be considered in any way as an endorsement of the particular sands. There are numerous other sands with nearly identical properties that might be mentioned.

II. General properties of molding sands

A brief account of the general principles involved in the use of sand molds will be worth while. A casting is ordinarily made by pouring the molten metal into a mold which consists essentially of a cavity of suitable shape and size in a quantity of sand. The sand in such a mold may be either moist or dry or only the sand which forms the surface walls of the cavity may be dry. By far the greater amount of sand used in the foundry is used in the moist, or green, condition. The molding qualities of a sand and its other characteristic properties are determined on the sand in this condition. For this reason, most of the discussion presented deals with the green sand.

The term "sand" is used in various ways, usually in a qualified sense, for example, glass sand, to indicate a specific usage. In the foundry, the term is restricted to sand consisting entirely of grains of silica. A natural molding sand consists essentially of the grain material, made up of grains of silica, and the bonding material, which is largely clay.

In addition, there may be small amounts of other substances the character of which depends upon the nature of the rock from which the sand originated. These substances, usually undesirable, are sometimes referred to as the "fluxing ingredients".

The essential characteristics which any molding sand must possess are apparent to any one who observes the making of a mold and its use in the casting of a metal. Naturally, the sand must possess moldability when wet, or when "tempered", with a suitable amount of water. The strength or cohesiveness of the tempered sand after being compressed or rammed is surprising. The need for considerable strength becomes apparent, however, as one continues his observations. The forming of an impression, accurate in all details, of a pattern and removing the pattern from the sand which has been rammed about it is only a small part of the story. The strength of the compacted sand must be sufficient to ensure freedom from crumbling of the sand from any part of the walls of the mold, especially from that portion which lies in the cope, that part which, when the entire mold is assembled, is inverted and forms the upper part of the mold cavity. Strength is also required for holding firmly in place the cores which are placed in the mold cavity and around which the molten metal solidifies to form cavities and openings in the finished casting. Strength in the sand is especially necessary to withstand the erosive and cutting action of the molten metal as it is poured into the mold as well as to withstand the pressure of the metal itself within the mold.

Although a molder always makes special provision for the "venting" of a mold for the escape of air and other gases during pouring, it is evident, even to a casual observer, that the sand itself must play an important part in the venting of the mold during and subsequently to pouring. Copious amounts of air and steam escape from the surface of the sand. The property of the sand which permits this to occur is termed "permeability" and, while this is related to the porosity of the sand, the two are not synonomous.

Occasionally one sees in a foundry, castings which, when taken from the mold, are heavily encrusted with burned-on sand. The removal of this is tedious and often difficult and the surface of the underlying metal is often rough and unsightly and details of the pattern are not accurately reproduced. In such cases, it is evident that the sand, as a whole, was not sufficiently infusible to withstand the heat of casting. This infusibility is a property of molding sand to which much importance is attached. It is related to certain constituents, especially the fluxing constituents and not to the grain of the sand.

While the characteristics described cover the salient features of good molding sands, the list is by no means complete. It is evident, however, from the discussion that molding sand is a more or less specialized product, the selection and preparation of which should be carefully supervised and controlled. The testing methods by which this can readily and accurately be done form much of the subject matter of this circular.

III. The determination of the properties of molding sands; test methods

1. Preparation of sands for study

As in all testing work, representative samples must always be selected. The Committee on Molding Sand Research of the American Foundrymen's Association has made definite recommendations for suitable methods for the sampling of sands, in order that representative samples may be obtained.

Most of the tests are made on moist (tempered) sand. It is necessary, therefore, that there should be a specific method for tempering. The method used by the Bureau is as follows: A sample of the sand, sufficient in amount for all of the tests, should be dried in an oven at a temperature between 105°C and 110°C (221 to 230°F) for at least one hour. The sample of sand is allowed to cool and then tempered with water. It is usually desirable to temper different portions of the dried sand with different amounts of water; three are generally used, the smallest amount being chosen so as to leave the sand a little too "dry". The amounts used for the other portions are increased progressively and one must be guided largely by experience in their choice. Thorough mixing and uniform distribution of the water throughout the sand are necessary. The sand after tempering should be kept in an air-tight container (for example, a glass quart jar with screw top and rubber seal) for 24 hours before being used for testing purposes.

a. Determination of moisture

The water content of the tempered sand should be determined before further tests are carried out. This is done by drying a weighed sample (100 g) on a watch glass or other open dish in the same manner as the original drying of the sand. The dried sample is allowed to cool in a dessicator or covered vessel and then reweighed. The loss, of course, is numerically equal to the percentage of water contained in the tempered sand.

The amount of water used in tempering most commercial molding sands for testing purposes lies between 3 and 9 per cent (approximately).

A rapid method for determining the water content of a sand is often very desirable. A method by which satisfactory results have been obtained at this Bureau consists in mixing 50 ml of alcohol with 100 g of the tempered sand in a wide evaporating dish, igniting the alcohol and allowing it to burn until the flame is extinguished. Continuous stirring of the sand during the burning is advisable. The difference between the weight of the sample after cooling and the initial weight gives the water content in per cent and agrees well with the value obtained by drying in the oven as is shown by the following results (Table 1).

Table 1 - Water content of tempered sand obtained by two methods

Sand	Water Content	
	Oven Drying	Ignition with Alcohol
	per cent	per cent
Albany 00	5.3	5.6
Dorner	4.7	4.7
Pettinos	5.9	5.8
Steel Foundry	7.5	7.5

2. Fineness

The determination of the fineness of a molding sand is undoubtedly the most important single test which is made on a sand. Although fineness is a measure only of the relative size of the constituent particles of the sand, the information gained by a test of this kind is much broader than the name would suggest, and much can be inferred from the results as to the other important characteristics of the sand, viz., permeability, strength, surface finish of castings, etc.

The method is essentially one of "mechanical analysis" and consists usually of a combination of floatation and sieving. By means of floatation, particles whose diameter is approximately less than 20 microns, (1 micron (μ) = 0.001 mm) are separated from those having a greater diameter. The fine-grained portion consists largely of the bonding clay of the sand as well as some other very fine material and is designated by the name 'clay substance'. The coarser material, consisting essentially of the silica, is termed the "grain". By means of sieving, the relative amounts of the predominating grain sizes or 'texture' of the grain material, is determined after drying.

Since the bonding power of a molding sand is directly related to, and the permeability may also be affected by the clay content, the determination of the clay substance is of very considerable importance. The quantity of clay substance may be determined in various ways, most of which depend upon the difference in rate of the settling of particles of different sizes when suspended in water.

The test is carried out on a 50 g sample of the dried sand. The separation of the fine clay particles from the remainder of the material is expedited if the water used for the suspension contains a small amount of sodium hydroxide which assists in deflocculating the clay. The common approved practice is to use 25 ml of a one per cent aqueous solution of sodium hydroxide diluted with distilled water to 500 ml. The sand and water are placed in a glass container which should be securely closed. A quart glass jar such as is in common use in the household is generally used. It is necessary to agitate the sand-water suspension very thoroughly so as to separate the clay completely from the sand grains. A simple device which utilizes a small electric stirrer such as is used for preparing soft drinks is shown in Figure 1. Five minutes' stirring with this device has been found ample in most cases. A motor-driven device for repeatedly turning the jar upside down is also used and has been recommended by the American Foundrymen's Association. The process is continued for one-hour at a rate of 60 reversals of the bottle per minute.

In order that different workers may obtain comparable results, it is necessary that a definite method of separation of the suspended clay from the coarser particles be carefully followed. After stirring the sand-water mixture, the top of the container is removed, adhering particles washed into the jar and the jar filled with distilled water to a reference mark near the top, allowed to stand for 10 minutes and the water, with the suspended clay, is removed by siphoning until the level has been lowered 5 inches below the initial level. The siphon is then removed, the jar filled with distilled water, and the water agitated sufficiently to bring the grain into suspension. The jar and contents are then allowed to stand for 10 minutes and the siphoning repeated. The operation is repeated again and again with a settling periods of 5 minutes, however, instead of 10 minutes, until the supernatant water becomes entirely clear after standing for 5 minutes. By this means all particles which settle at a rate of less than 1 inch per minute are separated from the remainder. The finer particles removed by siphoning constitute the "clay substance". The remainder is the "grain". This is removed from the jar, filtered, dried and weighed. The difference between the two weights of the sample represents the

clay substance; no attempt is made to recover the clay which is carried off by the water in siphoning.

The various amounts of clay substance determined in this manner on samples of a number of commercial molding sands are given in Table 2.

Table 2 - Clay substance in various commercial foundry sands

Name of Sand	State	Clay Substance
		per cent
Albany, #00	New York	12.4
Downer	New Jersey	11.6
Downer, (open hearth)	do	3.6
Lumberton	do	20.0
Pettinos	do	15.0
Red gravel (backing sand)	Ohio	19.8
Zanesville	do	15.8
Rush Run	do	24.8
Campbell's (core)	Virginia	3.2
Ottawa (synthetic molding sand)	Illinois	10.0
French molding sand	(foreign)	19.2

The bonding power of molding sand decreases with use. This decrease is caused primarily by the driving off of the chemically combined water. The bond is practically destroyed in "burnt" sand. The need for the treatment and systematic "control" of sands within the foundry is thus apparent.

The grain remaining after the clay substance has been removed is dried and the distribution of grain sizes is determined by sieving. The sieves (shown in Table 3) selected from the Bureau of Standards series are used for this purpose.

Table 3 - Sieves selected from the Bureau of Standards series for foundry use

Sieve No.	Opening Inch	Opening mm
6	0.1320	3.360
12	.0661	1.680
20	.0331	0.840
30	.0232	.590
40	.0165	.420
50	.0117	.297
70	.0083	.210
100	.0059	.149
140	.0041	.105
200	.0029	.074
270	.0021	.053

The sieves, which are 8 inches in diameter and of the half-height construction, are nested securely together in order with the coarsest at the top and a pan beneath the finest (No. 270). The sample is placed on the upper sieve and covered and the whole assembly shaken by means of a Rotap mechanical sieve shaker or its equivalent for a period of 15 minutes. The amount remaining on each sieve is weighed and its percentage of the sample calculated. The approximate grain size of any of the various fractions secured in this manner is assumed to be that of the size of the openings of the sieve immediately preceding the one on which the sample was retained.

The results of sieve analysis of a number of commercial foundry sands are given in Figure 2, in which the percentage of the "grain" has been plotted against the approximate grain size as indicated by the sieve openings. The arbitrary value of 3 has been assigned by the Committee on Molding Sand Research, American Foundrymen's Association, to material which fails to pass through the first sieve (No. 6) and 300 to the particles which pass the finest sieve and are caught on the pan. Two further arbitrary changes have been made in that the number 5 has been assigned to those grains which pass sieve No. 6 and remain on sieve No. 12 and 10 to those grains which pass sieve No. 12 and remain on sieve No. 20. By means of the diagrams in Figure 2, the difference in the distribution of grain sizes of three representative foundry sands is clearly shown.

For purposes of classification and specification, an average grain fineness number is often advantageous. This is readily obtained as is shown in Table 4, the calculation being analogous to the method used for determining the center of mass of a system of rigidly connected bodies. The average grain fineness number is then approximately proportional to the total surface area of the particles of a unit weight of the material.

Figure 1. - Stirrer used in the separation of the clay and grain of a molding sand

The suspension of sand and distilled water (which contains a small amount of sodium hydroxide) is forced by the stirrer past the stationary "hair-pin" baffles which are integral with the screw cover.

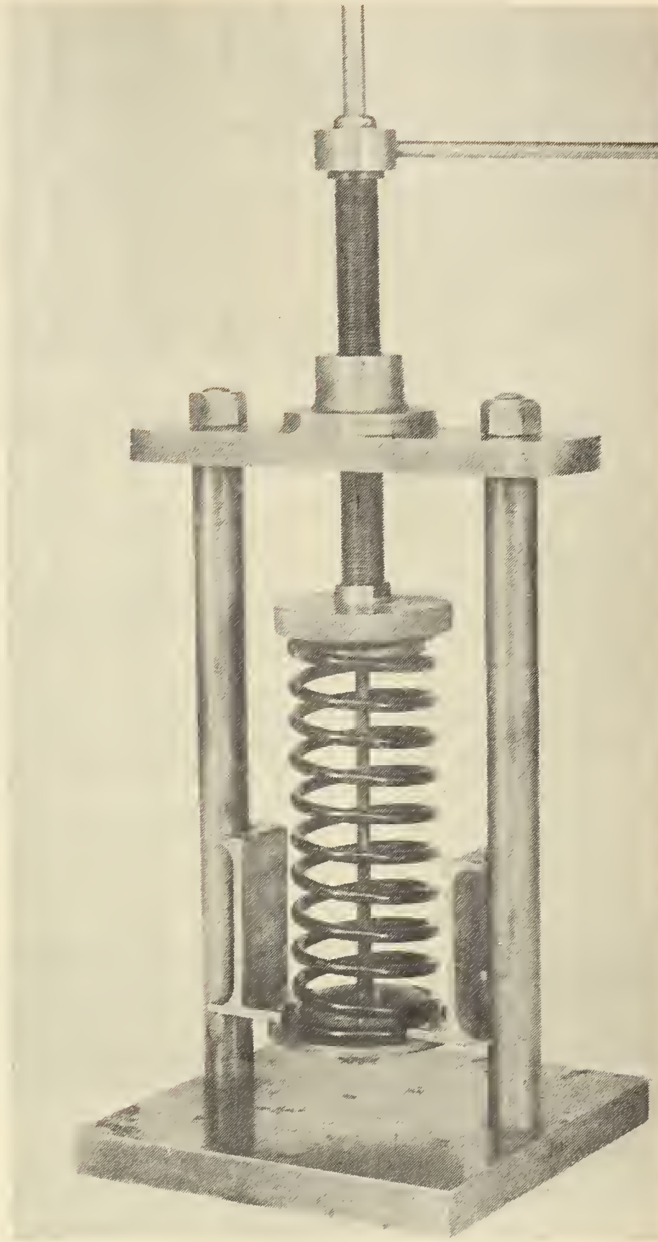
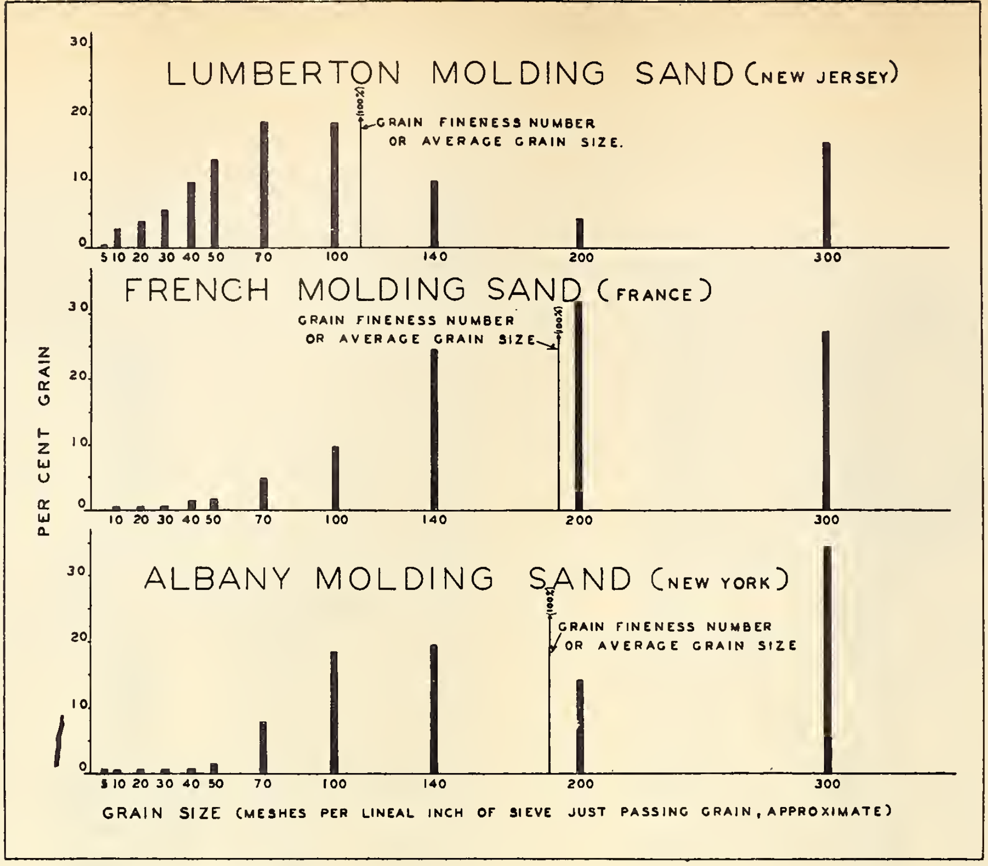


Figure 3. - Device used in determining the compressive strength of sand specimens

The specimen is placed beneath the compression head and the spring compressed by turning the handle. The distance to which the graduated rod projects as the spring is compressed, indicates the compressive stress(lb./in.^{2}) transmitted to the specimen. When the specimen fails, the projecting rod remains fixed in position.



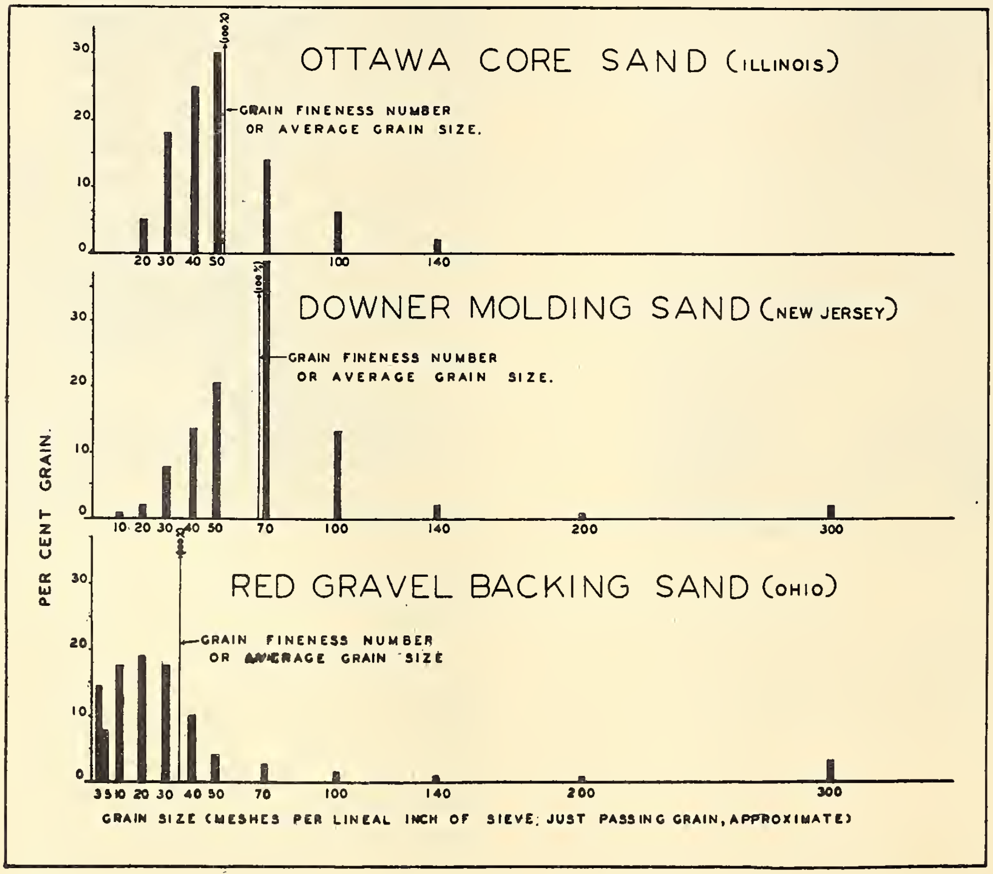


FIGURE 2 - DISTRIBUTION OF THE GRAIN IN A NUMBER OF COMMERCIAL FOUNDRY SANDS. AFTER THE CLAY HAS BEEN REMOVED THE RECOVERED GRAIN IS DRIED AND THE VARIOUS FRACTIONS SHOWN ABOVE ARE SEPARATED BY SIEVING. IN PLOTTING THE DIAGRAMS, THE TOTAL GRAIN HAS BEEN CONSIDERED AS 100 PER CENT (NOT THE PERCENTAGE SHOWN IN TABLE 10).

Table 4 - Calculation of grain fineness number of a foundry sand (Dorner molding sand)

Sieve No.	Amount (A) Retained on Sieve	Relative Grain Size (S)[a]	Product, AS
	per cent		
6	0.0	3	0
12	.0	5	0
20	.8	10	8
30	1.2	20	24
40	3.4	30	102
50	4.4	40	176
70	29.6	50	1480
100	32.2	70	2254
140	12.2	100	1220
200	1.5	140	210
270	0.4	200	80
Pan	1.3	300	390
	Total(ΣA) = 87.		Total(ΣAS)= 5914

Average grain fineness number

$$\Sigma AS \div \Sigma A = 5914 \div 87 = 67$$

(a) Proportional to the reciprocal of the grain diameter.

The results plotted in Figure 2 show the relation of the average fineness number to the distribution of grain sizes of the sand.

Efforts have been made to represent grain size distribution numerically in a manner similar to average grain fineness. If the complete results of the mechanical analysis by sieving are available, a numerical "distribution factor" is, of course, not needed. A method which is mathematically sound consists in an extension of that used in Table 4.

Instead of the summation of the products, AS, the summation of the products, AS^2 is divided by the mass (ΣA), that is, the total percentage of grain. A much simpler method consists essentially in designating the number of consecutive sieves which retain at least 75 per cent of the material. In case of lack of complete results of sieving, such a factor, together with the average fineness number, would serve to define a sand, closely enough for practical use.

3. Strength

(a) Compressive strength

It was pointed out that "strength" is one of the important characteristics of molding sand. In a strict sense, the term, strength, should be restricted to the molded sand specimen and not to the loose sand. Of the various methods in use, the one which determines the strength of the molded specimen in compression is preferred and used most frequently at this Bureau. The specimen consists of sand which has been tempered in the manner described, compacted in a known and reproducible manner, into a cylinder, 2 inches in diameter and 2 inches in height (tolerance ± 1/16 inch in height).

The sand is compacted by ramming within a cylindrical tubular container, by means of a freely sliding (falling) weight (17.5 lb.), so arranged that the entire cross-section of the cylinder is uniformly affected. Three blows, under a 2-inch drop of the weight, are used. If the height of the rammed specimen does not come within the prescribed limits a new specimen is made with a slightly different initial amount of sand.

The device for determining the compressive strength is of relatively simple construction (Figure 3), the calibrated spring being the most important feature. By turning the handle and compressing the spring, load is applied through the movable compression head to the sand specimen at a rate of from 20 to 40 pounds per minute until the specimen collapses. The distance through which the spring has been compressed at the time the specimen broke is shown by a calibrated rod which remains fixed in position. From the calibrated rod the pressure required to break the specimen may be read in pounds per square inch.

Various other means for measuring the compressive strength of sands have been devised and are to some extent used. In all of them, specimens of the above form are used.

For any particular molding sand, the strength is dependent upon the amount of water contained and the compactness of the sand. For specimens prepared by ramming in the manner described, the water content is the principal controlling factor. The results shown in Figure 4 illustrate this for a number of commercial molding sands.

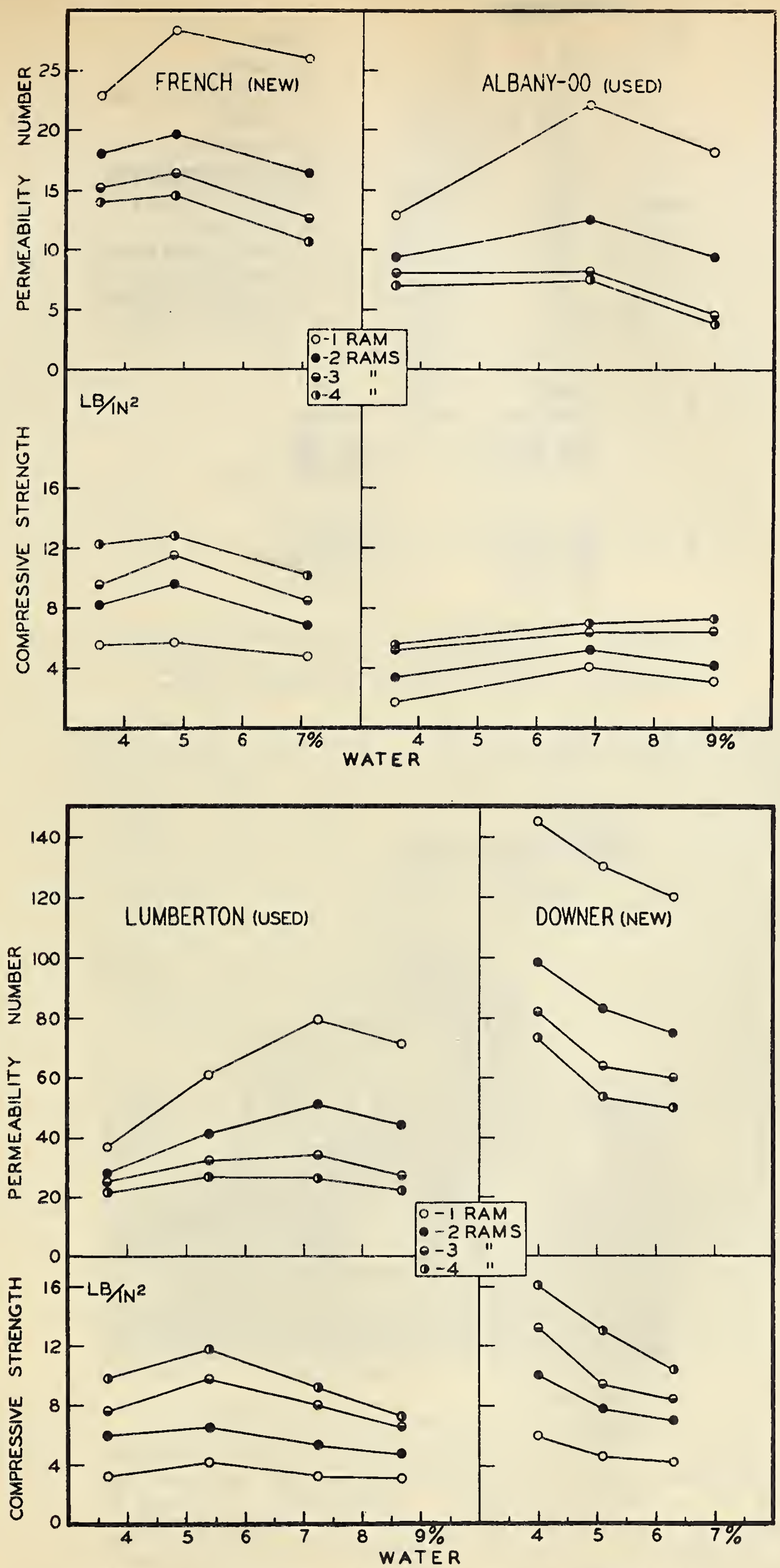


FIGURE 4 - COMPRESSIVE STRENGTH AND PERMEABILITY OF A NUMBER OF COMMERCIAL MOLDING SANDS IN EACH CASE FOUR DIFFERENT DEGREES OF COMPACTNESS (RAMMING) HAVE BEEN USED.

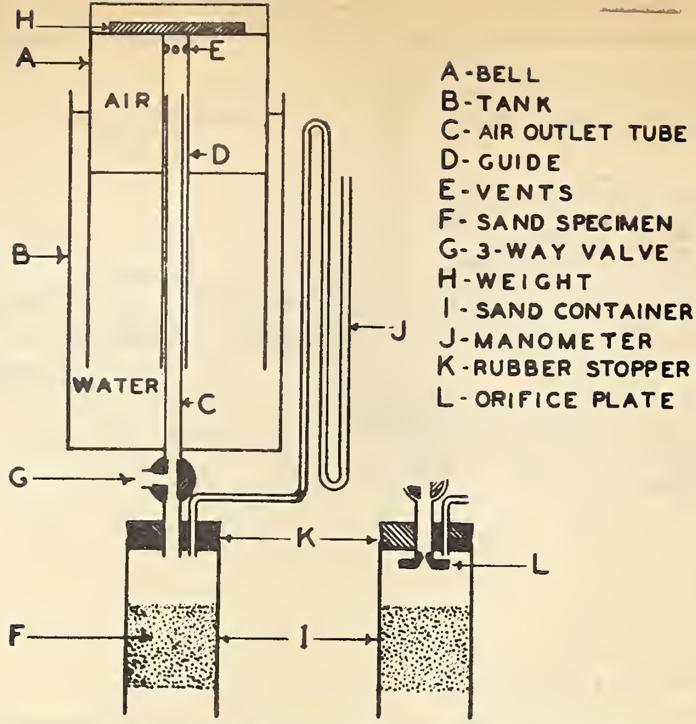


Figure 5. - Diagram showing the essentials of the method used in determining permeability of sand specimens
The modified method which depends upon the use of a calibrated orifice, is shown in the smaller diagram.

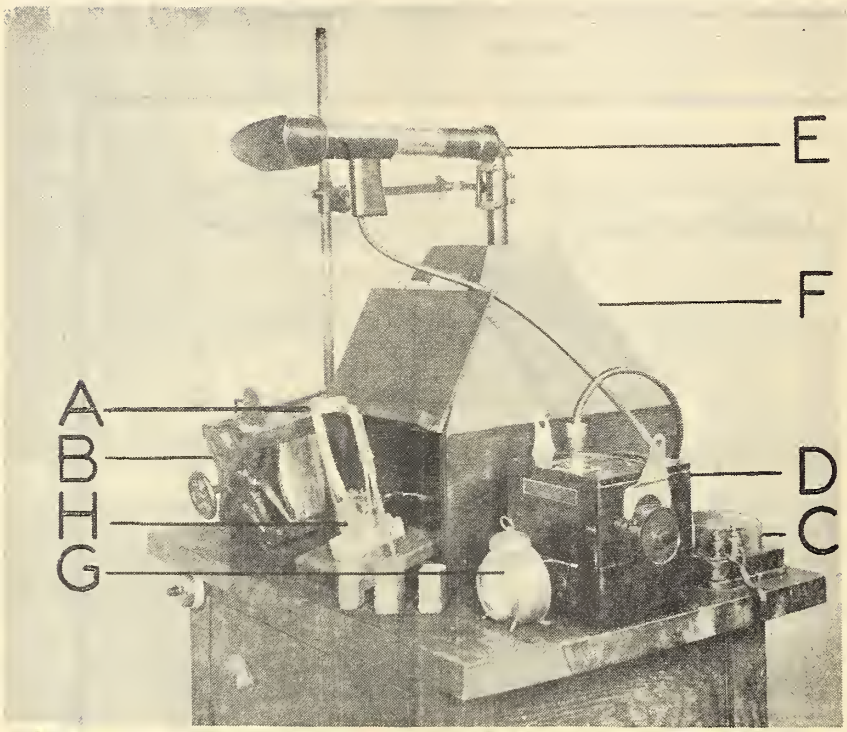


Figure 6. - Apparatus used in determining the "sintering point" of foundry sands

A is a U shaped yoke, between the free ends of which, is stretched the platinum ribbon (resting on the sand specimen, H) which is heated by an electric current controlled by the carbon-plate rheostat, B, and read by means of the ammeter C (range, 50 amperes). D is used in connection with the optical pyrometer E for measuring the temperature of the hot platinum ribbon and F is the light-proof cabinet used to cover the specimen and heating element during the test.

(b) Other tests

The American Foundrymen's Association, through its Committee on Molding Sand Research, has approved the compression test in all cases, as in disputes, in which comparisons of the results of different investigators are necessary. The determination of the tensile and the shearing strength in place of the compression strength, is in rather wide usage. A method, formerly widely used, consists essentially in slowly sliding a straight bar of uniform rectangular cross-section molded from the sand over the edge of a supporting table so that the one end overhangs. The weight of the maximum overhanging portion is determined. On account of the difficulty of producing specimen bars of uniform and reproducible properties, the use of this method is decreasing.

Since the strength of a molding sand is primarily dependent upon the bonding material, any test which gives information on the nature and amount of this bonding material should be of interest. Much of the bonding substance is colloidal clay. Like colloids of this type, it has the property of "adsorbing" the coloring matter from dye solutions. Hence, the comparison of the color of two glass tubes, one of which contains a water solution of a dye (crystal violet) and the other the same amount of a similar solution which has been shaken up with a sample of the dried molding sand will give some information on the colloidal character of the "bond" of the sand. The color of the dye solution which has been shaken up with the sand is diminished, the degree of dimunition (measured by comparison with the unchanged dye solution of similar concentration) gives qualitative information on the bonding characteristics of the clay. In carrying out the test, it is advisable to add a small amount of an electrolyte (for example, acetic acid) to accelerate the settling of the colloidal substance and obtain a clear solution. Considerable experience, however, in the use and testing of molding sands is necessary in applying the information. The test is unreliable for used sands, especially if they have been treated by the addition of various substances as is common practice in certain lines of foundry work.

4. Permeability

A measure of the relative permeability of a chosen sand is obtained by measuring the rate of flow of air under pressure through a standard specimen. The specimen is identical with that prepared for the determination of compressive strength, with the important exception, however, that it is not removed from the container in which it is rammed. In routine testing

the determination of compressive strength and permeability are made on the same specimen, permeability being determined first. The time required for forcing 2000 cm3 of air through the standard specimen under a known pressure is measured with a stop watch. From the data obtained is calculated the volume of air passing through a unit volume of sand (a cube, 1 cm on each edge) in one minute under a pressure of 1 g per cm2. This is, by definition, the permeability of the sand and may be expressed by the formula:-

$$P = \frac{v.h.}{p.a.t.}$$

in which P = the permeability "number",
v = volume (cm^3) of gas (air) forced through the specimen,
h = height of sand specimen (cm),
a = cross-sectional area of sand specimen exposed to the gas (cm^2),
p = pressure used in forcing the air through the sand (g),
t = time (minutes).

By substituting the values for v, h and a in the formula (2000 cm^3, 5.08 cm and 20.27 cm2, respectively), the formula reduces to

$$P = \frac{501.2}{p.t.} .$$

The pressure is read directly by means of a manometer.

A diagram showing the essentials of the apparatus is given in Figure 5.

The determination of permeability can be greatly expedited, for routine testing work, by a relatively simple modification of the apparatus and with only slight sacrifice in accuracy. The modification consists essentially in controlling the rate of flow of air from the reservoir to the sand specimen by inserting in the supply tube a plug having an orifice of known diameter and shape. To insure permanence against corrosion and other possible deterioration, gold is used as the material surrounding the orifice. In this modified method, it is necessary only to read the pressure at which the air is being forced through the sand and obtain the corresponding permeability number from a table based upon previous determinations.

Various precautions depending upon the condition of the sand tested are sometimes necessary in the determination of the permeability number. For example, a screen (60 mesh) is used to

support specimens of dry sand containing little or no bonding material. In determining the permeability of baked specimens of a sand containing bonding material, a special holder is used and it is necessary to "seal" in the specimen with mercury and a rubber gasket to prevent the flow of air between the specimen and the adjacent wall of the container.

Permeability and strength of molding sands are, in general, opposing properties. Conditions such as an abundance of bonding clay or a high degree of compactness, both of which are favorable to high strength, are conducive to low permeability numbers. The effect of progressive ramming in increasing the compressive strength of molding sand and simultaneously decreasing the permeability is clearly shown in Figure 4. The general effect of water content (degree of tempering) on the strength and permeability is shown, as well as the rather wide differences which may exist between different sands on account of the differences in their inherent characteristics, clay content, grain sizes, etc. The need for strictly defining the conditions of preparation of the specimens upon which strength and permeability are to be determined is apparent.

5. Sintering

Although silica, the chief constituent of molding sand, undergoes two crystalline transformations on heating (870°C, to tridymite, and 1470°C, to cristobalite), it is otherwise stable until the melting point, 1710°C ± 10 (3110°F) is reached. This temperature is well above the temperatures reached in the casting of iron and non-ferrous alloys. The nearest approach is in the making of steel castings. A casting steel becomes completely molten on heating to approximately 1500°C (2730°F).

The refractoriness of a molding sand under conditions obtaining in the casting of metals is dependent primarily upon the amount and nature of "fluxing constituents" and to some extent the bonding material. A determination of the melting temperature is seldom necessary. However, the determination of the temperature at which a sand sinters or "burns on a casting is important. The method used for this determination consists in holding a ribbon of platinum, maintained at a chosen temperature by passing an electric current through it, against the surface of a specimen of the sand. The specimen is prepared in the manner already described for the determination of strength and permeability. After removal from the cylinder in which it was rammed, enough sand is cut away to reduce the dimensions to 2 inches by 2 inches by 1 inch and the specimen is dried for

1 hour, at 105 - 110°C. The current is adjusted so as to produce the chosen temperature, as determined by an optical pyrometer of the "disappearing-filament" type, proper corrections for emissivity and other conditions being made. The ribbon is then held for four minutes against the narrow face of the specimen by the weight (170 g.) of the ribbon holder, and then examined after the current has been cut off for evidence of sintered sand particles sticking to it. The operation is repeated, each time at a temperature 25 degrees higher than the preceding one and on another portion of the specimen, until particles of the sand may be seen to have sintered to the ribbon. The temperature at which this occurs is taken as the "sintering point" of the sand. The apparatus is shown in Figure 6. Table 5 gives the test results on representative commercial molding sands. It will be noted that there is a fairly consistent relationship between the average grain size and the sintering temperature. This is definitely lower for sands of finer grain size than for those of coarser grain size.

Table 5 - Sintering point of various commercial molding sands

Sand	Sintering Temperature		Clay Substance	Average Grain Fineness Number
	°C	°F(a)	Per Cent	
French molding	1175	2145	19.2	192.
Albany #00	1200	2190	12.4	188.
Zanesville	1200	2190	15.6	196.
Lumberton	1200	2190	20.	111.5
Rush Run	1225	2235	24.8	110.
Pettinos	1225	2235	15.	83.
Ottawa (added bond)	1250	2280	10.	50.
Downer	1250	2280	11.6	67.5
Red gravel (backing sand)	1300	2370	19.8	35.5
Downer open-hearth	1325	2415	3.6	67.
Campbell core	1400	2550	3.2	46.

(a) "rounded off".

The approximate pouring temperatures in ordinary foundry work are given in Table 6.

Table 6 - Pouring temperatures for foundry castings (approximate)

(The pouring temperature is varied with size of casting and other factors.)

Castings	Pouring Temperature deg. C	Deg. F
Aluminum alloys	700 - 780	1290 - 1435
Brass	1000 - 1320	1830 - 2410
Cast iron (stoveplate)	1260 - 1425	2300 - 2600
Malleable cast iron	1425 - 1550	2600 - 2820
Steel	1525 - 1600	2750 - 2910

6. Miscellaneous

a. Hardness of mold surfaces

The determination of the surface hardness of green-sand molds is a test which is coming into favor. The results, however, are more characteristic of the mold and particularly the compactness of the sand produced by ramming, than of an inherent property of the sand. The test is somewhat analogous to that of the Brinell hardness testing of metals. A small portable device having a flat base, through which projects the hemispherical end (indentor) of a movable plunger acting against a spring, is pressed against a flat surface of the mold or sand specimen until there is close contact. The depth to which the indentor penetrates the sand is shown on a graduated scale. The inverse of the depth of penetration has been accepted as a measure of the hardness of the sand mold surface; a penetration of 0 corresponds to a hardness number of 100 and vice versa. To the experienced molder the results are indicative of the strength and permeability of the mold, particularly the surface layer.

The results summarized in Figure 7 illustrate the relationship between the compressive strength of specimens of four commercial molding sands, as determined in the manner previously described, and the surface hardness of the same specimens. The surface hardness values shown in Figure 7 are also related to the permeability values, shown in Figure 4.

b. Core sands

In general, considerably greater strength is required in sand cores than in sand molds. In order to obtain the greater bonding strength various artificial 'binders' are added to the sand. Silica sand is usually used, although molding sand

is used sometimes. The molded core is usually baked in order to develop the required strength. The permeability of cores of baked molding sand is determined in the manner already described and the strength is usually determined by breaking in tension a briquet somewhat similar in shape to those used in testing cement. In the preparation of test specimens of cores, the same care and procedure should be used as in the making of the cores themselves. These tests are of greatest value in the study of the properties of core binders and for such tests a carefully selected, washed and dried silica sand consisting of well-rounded grains between 40 and 70 mesh in size, with at least 95 per cent of the 70-mesh size, is used.

c. Shape of grain

Although much study has been devoted to the subject of grain shape, no definite statements supported by the results of tests can be made as to the practical aspects of this phase of the subject. The grain shapes of foundry sands are usually classified as: angular, subangular, rounded and compound. By some writers, the rounded grain is considered as the basis of the "ideal" molding sand.

d. Chemical analysis

A determination of the chemical composition of a molding sand is not required in ordinary testing. In the study of new deposits and of sands which are, in certain respects, unsatisfactory, chemical analysis must often be relied upon. The determination of the nature and amount of the "fluxing constituents" is often helpful in this respect. A sand may be unsuitable for foundry use because of the presence of particles of undecomposed mica or of feldspar, both of which result in a low sintering point for the sand. The determination of calcium, sodium or potassium by chemical analysis is useful in such cases in establishing the cause of the inferiority of such sands.

IV. Grading and choice of sands

1. Grading

A number of classifications of molding sands have been recommended by the Committee on Molding Sand Research of the American Foundrymen's Association. The class designations serve to define rather closely a sand for foundry use. In addition to giving the grain fineness number (page 9) and the grain shape (page 16) the sand may be classified according to the grain fineness and the clay content. These classifications are given in Tables 7 and 8.

Table 7 - A.F.A. classification of sands according to grain fineness

Class Designation	Range in Grain Fineness Number[a]
1	200 to 300 (incl.)
2	140 " 200
3	100 " 140
4	70 " 100
5	50 " 70
6	40 " 50
7	30 " 40
8	20 " 30
9	15 " 20
10	10 " 15

(a) In all cases, except No. 1, the range of fineness numbers extends up to but does not include the number marking the upper limit.

Table 8 - A.F.A. classification of molding sands on the basis of clay content

Clay Designation	Clay Content per cent (a)
A	0 to 0.5
B	0.5 " 2
C	2 " 5
D	5 " 10
E	10 " 15
F	15 " 20
G	20 " 30
H	30 " 45
I	45 " 60
J	60 " 100

(a) In all cases, the range of percentage of clay extends <u>to</u> but does not include the upper limit.

2. Choice of sands

Only very general recommendations can be given to cover the choice of sands for specific uses. The information given in Table 9, which is based largely upon experience, is intended as suggestive rather than in the nature of a categorical reply to the question often asked of this Bureau as to the proper sand for a certain specific use.

Table 9 - Sands for specific uses

Casting Material	Casting Rel. Size	A.F.A. Sand Class	Compressive Strength lbs/sq.in.	Permeability Number
Brass	light	1; D or E	3 - 4.5	8 - 12
"	medium	2; E	3 - 5	10 - 17
"	heavy	3; E	3.5- 6	17 - 25
Aluminum alloys	light,) medium)	1; E, F or G	3 - 7	8 - 15
"	heavy	1 or 2; E or F	4 - 8	10 - 20
Cast iron	light	2,3 or 4; E	3 - 8	15 - 65
"	medium	4 or 5; E	4 - 9	65 - 100
"	heavy	5,6 or 7; E or F	6 - 10	75 - 150
Malleable iron	light	3; E or F	3 - 8	20 - 50
"	medium	4; E	4 - 9	50 - 100
"	heavy	5,6 or 7; E	6 - 10	90 - 125
Steel	light	5; C	4 - 8	100 - 150
"	medium	5 or 6; C	4 - 8	125 - 200
"	heavy	6 or 7; C	4 - 8	150 - 250

For convenience in reference most of the data on molding sands given in the course of the preceding discussion has been collected in Table 10.

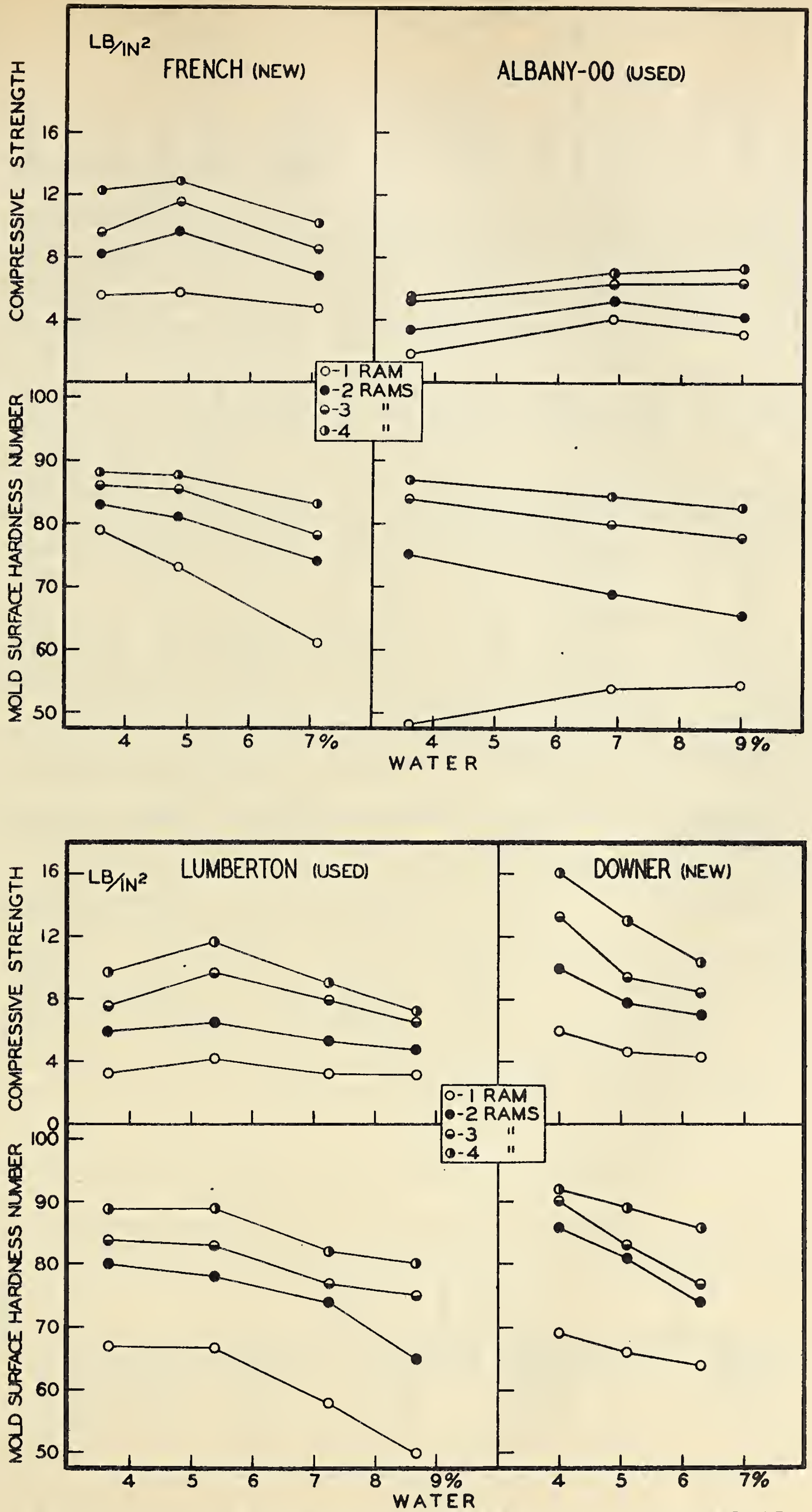


FIGURE 7 - MOLD-SURFACE HARDNESS AND COMPRESSIVE STRENGTH OF A NUMBER OF COMMERCIAL MOLDING SANDS. COMPARE FIGURE 4

Table 10. - Results of tests on various commercial molding sands

No.	State of origin	Designation of sand (1)	Results of sieve analysis, per cent retained on sieves													Physical properties					Grade			Use in casting	
			6	12	20	30	40	50	70	100	140	200	270	Pan	Clay	Moisture Per cent	Permeability	Compressive Strength lbs/sq.in.	Sintering point °C	Grain fineness number	Grain class	Clay class	Grain shape	Material	Relative size
1	N. Y.	Albany,00	0.0	0.1	0.2	0.3	0.4	0.8	1.6	7.0	16.2	17.3	12.8	30.8	12.4	3.5 5.2 7.2	14.7 14.5 14.3	6.0 5.4 4.8	1,200	188	2	E	Sub-angular	Cast iron, brass or aluminum	Light
2	Ohio	Zanesville	—	—	.2	.1	.3	2.0	6.9	10.0	8.8	8.7	7.7	38.9	15.8	4.1 5.1 7.8	7.7 9.8 10.8	4.3 4.3 4.1	1,200	196	2	F	Compound	do	do
3	N. J.	Pettinos	--	--	--	--	2.0	3.0	23.6	28.6	18.0	6.0	0.8	3.0	15.0	2.8 4.3 6.5	72 93 87	6.2 8.8 6.2	1,225	83	4	F	Sub-angular	do	Heavy
4	do	Downer	--	--	.5	1.6	6.4	12.3	18.1	34.2	11.5	1.5	.5	1.6	11.6	3.3 5.3 7.4	102 88 77	10.2 4.9 3.0	1,250	67.5	5	E	do	Cast iron and steel	do
5	do	Lumberton	--	.3	2.0	3.0	4.1	7.7	10.3	14.5	14.8	7.7	3.1	12.2	20.0	3.6 5.8 7.2	19 38 29	6.7 6.8 6.4	1,200	111.4	3	G	do	Brass, cast iron	do
6	Ohio	Red gravel	11.6	6.1	13.7	15.1	14.2	7.8	3.2	2.0	1.3	0.8	0.5	3.0	19.8	3.6 4.9 7.5	235 780 440	too dry 6.4 7.0	1,300	35.1	7	F	do	Molding	do
7	Va.	Campbell's core sand	--	0.3	1.6	4.5	15.6	39.9	24.2	7.0	1.8	.6	.3	1.0	3.2	Dry	287	--	1,400	46	6	C	do	Cores	---
8	Foreign	French	--	--	0.1	0.1	0.1	0.9	1.4	3.7	7.4	19.6	25.3	21.8	19.2	4.1 6.2 7.4	25 23 30	13.2 4.6 9.0	1,175	192	2	F	do	Statuary bronze, etc.	---
9	N. J.	Downer open hearth and core sand	--	--	.6	1.6	5.4	14.3	21.9	30.6	17.5	3.0	0.5	0.3	3.6	3.4 5.1 7.2	156 146 138	1.6 1.6 2.0	1,325	67	5	C	do	Steel	---
10	Ohio	Rush run	--	.2	.3	0.1	1.0	14.6	20.4	10.4	7.5	4.8	3.2	12.9	24.8	3.7 5.3 6.9	61 50 46	8.2 14.2 10.4	1,225	110	3	G	Angular	Iron	---
11	N. Y.	Albany,00	--	--	--	--	0.3	0.3	0.5	1.0	5.8	8.7	10.8	55.2	17.3	4.7 6.2 7.8	13.4 14 14	6.3 5.7 4.7	1,175	249	1	F	Sub-angular	Brass and aluminum	----
12	Ill.	Ottawa core sand	--	--	--	5.	18.	25.	30.	14.	6.	2.	--	--	--	Dry	95	--	--	50	5	-	Angular	Cores	---
13	do	Ottawa steel mold sand	--	--	--	--	--	--	90.	--	--	--	--	--	10.	1.7	65	8.8	1,250	50	5	E	Round	Steel	---
14	Mich.	Buchanan	--	--	.3	0.1	0.1	0.4	3.4	11.7	15.9	11.3	7.3	41.8	7.7	3.5 5.0 6.7	6.7 9.0 8.5	3.3 3.5 4.1	1,225	197	2	D	Compound	Cast iron, brass or aluminum	Light
15	Ala.	Tuscaloosa	--	1.0	.6	.6	.6	1.8	6.0	9.8	13.8	11.6	9.3	22.0	22.8	8.0	20.	3.2	--	162	2	G	--	Brass and cast iron	do
16	Miss.	Red molding	--	--	--	--	2.0	17.1	30.0	22.5	8.3	1.8	0.4	0.6	17.1	7.0	88	12.2	--	62	5	F	--	Steel	---
17	Tenn.	Molding	--	--	--	--	0.8	1.7	4.6	12.1	18.5	25.5	5.9	8.3	23.2	10.0	19.3	11.7	--	132	3	G	--	Brass and iron	Heavy
18	N. J.	South Jersey	--	0.2	.4	.6	1.9	7.3	17.7	27.1	14.5	4.4	3.1	6.2	16.6	7.5	40	9.0	--	92	4	F	--	Steel	---
19	Md.	Campbell	--	--	.3	.5	1.5	8.6	20.0	13.6	8.7	9.5	1.8	11.2	24.5	4.3 6.1 8.3	10.3 24.7 24.5	12.0 12.5 11.9	1,200	109	3	G	Sub-angular	Iron	---
20	do	Marlboro	2.6	.6	.9	1.0	1.4	2.0	5.2	6.1	7.4	38.7	9.0	19.4	5.7	3.9 5.8 8.1	26.9 31.0 29.0	2.7 2.8 3.5	1,250	155	2	D	do	Cast iron, brass or aluminum	Light
21	D. C.	Georgetown	--	--	--	--	--	0.2	0.4	3.4	7.1	22.4	15.4	27.3	23.7	3.1 5.3 7.2	4.4 7.6 11.6	7.7 11.0 13.7	---	201	1	G	do	Brass or aluminum	---

(1) All are molding sands unless otherwise designated.

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